ARMY-NAVY

EXPLOSIVES SAFETY BOARD

TECHNICAL PAPER NO.1

THE PRESENT STATUS OF THE AMERICAN TABLE OF DISTANCE

WASHINGTON, D.C.

1 JULY 1945

INTRODUCTION

This paper prepared by Colonel Clark S. Robinson, Ordnance Dept., U.S.A. has taken into account only those data which have reached the Army-Navy Explosives Safety Board to date. Much other data will later reach the Board, on past and future experiences, and undoubtedly the findings expressed in this study will be subject to modification. The classification of damage has been very difficult to make.

It is planned to undertake in the near future a comprehensive study of the prewar and war experiences, by a sub-committee of the Board, and, until this study is made, the findings expressed herein should be regarded as tentative and are not for official use, until incorporated in the Official Standards of the Army-Navy Explosives Safety Board.

The study does indicate that the trend is toward an increase in safety distances, and naturally so, since the more powerful explosives are now being used. Just what explosives of the atomic type will require makes the issuance of this paper more tentative than ever.

It should be noted that few conclusions are reached in this paper, the data being simply presented for whatever light they may throw on a complicated phenomenon.

F. H. MILES, Jr.
Colonel, Ordnance Department
President, Army-Navy Explosives
Safety Board

EXPLOSIVES SAFETY

The Present Status of the American Table of Distances

Previous to 1910, there was no recognized rule or table which specified safe distances from stores of explosives. And on account of the lack of regulation, large amounts of explosives could be and were collected and stored in close proximity to centers of population, with corresponding disastrous results when they blew up. In that year, however, there was produced by a competent group connected with the explosives industry, the American Table of Distances, which filled this need and which has served ever since as a basis for state explosives regulations and for the regulations of the armed services. While there is no way of knowing what savings in lives and property were accomplished by the general adoption of this Table, there can be no doubt that it has amounted to thousands of lives and millions of dollars.

The facts upon which the American Table of Distances was based included the experiences from over one hundred notable explosions, ranging in the amount of explosives involved to over 800,000 pounds. In the 35 years since 1910, however, there have been many additional accidental explosions, involving not only much larger quantities of explosives, but also the newer, more brisant, high explosives which did not exist before 1910. It therefore has become advisable to re-examine the evidence on which the Table was based and compare it with the new facts that have since become available, particularly in regard to the possibility of extending the Table to higher ranges on account of the manifold increase in the size of the stocks of explosives now handled and in regard to the possible effect on it of modern, military high explosives.

The stated object of the American Table of Distances was to establish distances between stores of explosives and the surroundings such that the hazard to the public and to public property would be reduced to a minimum. The accidents upon which it was based are described in detail in Assheton's "History of Explosions" as well as the procedure used in the preparation of the Table. See Table I.

Each explosion was studied in order to determine the maximum distance from the explosion at which structural damage was reported. No attempt was made to separate the damage to substantial structures from that to flimsy ones, nor was there any attempt made to classify the damage with reference to the kind of explosive involved. The actual damage itself was divided into two categories only, broken glass being one, and structural damage being the other. The explosions were also classified as to whether or not the explosion had taken place behind a natural or artificial barricade or shield.

There were 117 explosions listed. Of these, 92 reported structural damage, while 25 reported broken glass only. Of the 92 thus reporting damage other than broken glass, 67 involved structures of light frame construction, usually flimsy, while 25 were of substantial brick or masonry type. 37 of the 92 reported "minor damage" such as displaced doors, loose sheathing, cracked chimneys, and the like, while 67 reported "more serious damage", the structure either badly needing repairs or needing

TABLE I

Wt. of Explo-sive	Date	Place	Kind of Explosive	Reported Distance	Kind of Building	Kind of Damage	Distance Plotted
200 #	1882	Pembrey Burrows	Dynamite	75'	Light frame construction	Rafter broken	75'
200	1884	Ardeer	Dynamite	240'	Light frame construction	Roof broken	240'
500	1907	Pinole	Gelatin	225'	Light frame construction	Slight	225'
533	1902	Perranporth	Gelatin	300'	Light frame construction	Severe structural damage	300'
600	1882	Pembrey Burrows	N. G.	190'	Light frame construction	Roof damaged	190'
600	1904	Pinole	N. G.	300'	Light frame construction	Considerably shattered	300'
640	1907	Landing, N. J.	Guncotton	125'	Light frame construction	Considerably shattered	65'
650	1903	Uplee's Marshes	N. G.	180'	Light frame construction	Planking displaced	180'
700	1903	Gibbstown	Dynamite	150'	Light frame construction	Boards blown off	150'
720	1880	Faversham	Black powder	75'	Frame building, slate roof	Roof displaced	75'
760	1899	Upton Towans	N. G.	216'	Frame office building	Roof displaced	216'
900	1899	Upton Towans	Gelatin	150'	Frame laboratory building	Roof and planking displaced	150'
900	1909	Landing	Dynamite	150'	Light frame construction	Side blown in; roof displaced	75'
950	1904	North Branch	Dynamite	400'	Frame dwelling	Badly shattered	200'
1000	1902	Lower Hope Point	N. G.	150'	Light frame construction	Side blown in; roof displaced	75'
1000	1903	Uplee's Marshes	N. G.	192'	Light frame construction	Side partly blown in	192'
1080	1906	Ashburn	N. G.	160'	Light frame construction	Roof and sides damaged	160'
1300	1906	Ashburn	Gelatin	450'	Light frame construction	Gable ends pulled loose	450'
1300	1907	Lewisburg	Dynamite	375'	Light frame construction	Side pushed out	375'
1500	1903	Chattanooga	Dynamite	425'	Brick magazine	Door torn out; peak of roof separated	425'
1500	1909	Plymouth Meeting House	Dynamite	600'	Stone dwelling	Rafters broken; studding blown out	600'
1700	1906	Ashburn	Dynamite	220'	Light frame construction	Badly shattered	220'
2000	1879	Chilworth	Black powder	135'	Light frame construction	Boards torn off; rafters broken	135'
2100	1909	Umbogintwini	N. G.	1000'	Light frame construction	Roof sucked down; walls bulged	500'
2100	1904	Cliffe	N. G.	150'	Light frame construction	Roof wrecked	150'
2100	1905	Hazelton	Dynamite	400'	Residence	Front badly bulged	400'
2100	1908	Beaver Meadow	Dynamite	300'	Dwelling, frame construction	Portion of roof caved in	300'
2200	1906	Ashburn	Dynamite	580'	Brick factory building	Rafters broken; brickwork damaged	580'
2200	1890	Waltham Abbey	N. G.	285'	Substantial masonry building	Seriously damaged	285'
2200	1897	Ardeer	N. G.	500'	Light frame construction	Wall stove in	500'
2300	1907	Boulder	Dynamite	200'	Brick warehouse	Brickwork displaced	100'
2400	1904	Upton Towans	N. G.	315'	Light frame construction	Severely damaged	315'
2500	1906	Shenk's Ferry	Dynamite	600'	Frame office building	Boarding pulled loose	600'
2500	1892	Winsted	Black powder	500'	Frame dwelling	Front shattered	250'
2640	1894	Krummel	N. G.	657'	Brick factory building	Roofs uplifted	657'
3500	1898	Blackbeck	Black powder	312'	Heavy stone building	Fronts blown out	312'
3500	1908	Gibbstown	Nitrostarch	700'	Light frame construction	Side blown down	350'
3580	1902	Ardeer	N. G.	510'	Light frame construction	Minor damage	510'
4080	[illegible]	[illegible]	N. G.	[illegible]	Light frame construction	Walls and roof damaged	[illegible]
4100	1905	Ishpeming	N. G.	1500'	Light frame storehouse	Roof partly fallen in	750'
4210	1907	Barksdale	N. G.	500'	Light frame construction	Roof and sides weakened	500'
4400	1908	Louviers	N. G.	625'	Light frame construction	Roof plates displaced	625'
5000	1883	Furnace	Black powder	235'	Light frame construction	Roof fallen in; walls down	118'
5000	1907	Essex	Dynamite	850'	Brick church	Roof broken; plaster down	400'

TABLE I (Cont.)

Wt. of Explosive	Date	Place	Kind of Explosive	Reported Distance	Kind of Building	Kind of Damage	Distance Plotted
5800 #	1904	Schaghticoke	Black powder	450'	Frame building	Wall bulged; roof damaged	450'
6000	1905	Emporium	N. G.	600'	Light frame construction	Roof and ends stove in	600'
6080	1905	Marquette	Dynamite	750'	Frame power house	Rafters broken	750'
6350	1907	Pinole	Gelatin	625'	Power house	Shafting out of line	625'
6700	1909	Wilmington	Black powder	300'	Light frame construction	Severe shaking	300'
7000	1909	Vigorit	N. G.	300'	Light frame construction	Badly damaged	300'
7020	1879	Faversham	Black powder	900'	Wood factory building	Roof damaged; sides partly in	450'
7500	1887	Hounslow	Black powder	180'	Brick boiler house	Wall blown down	90'
8000	1907	Mt. Carmel	Black powder	600'	Light frame construction	Considerably damaged	300'
8000	1876	Herodsfoot	Black powder	450'	Brick factory; slate roof	Roof damaged; door blown in	450'
9670	1906	Barksdale	N. G.	850'	Wood frame boiler house	Boiler breaking caved in	850'
10,000	1854	Wilmington	Black powder	300'	Brick residences	Considerable damage	300'
10,000	1894	Pittsburgh	Dynamite	500'	Wood frame storehouse	Side collapsed	250'
10,000	1874	Regent's Park	Black powder	600'	City dwelling	Serious structural damage	600'
12,000	1889	Antwerp	Black powder	1110'	Brick pumping house	Roof off; wall down	1110'
12,375	1906	Thompson	Dynamite	500'	Frame roundhouse	Roof crushed in	500'
12,600	1906	Cobalt	Dynamite	543'	Shacks	Wrecked	543'
16,000	1864	City point	Black powder	495'	Light wooden buildings	Blown down	495'
20,000	1905	Steelton	Dynamite	550'	Brick power house	Windows broken	275'
20,000	1908	Holmes Park	Black powder	600'	Above ground magazine	Roof pushed down	600'
20,000	1908	Cle Elum	Black powder	850'	Frame dwelling	Roof damaged	850'
21,750	1909	Wilmington	Black powder	525'	Brick storehouse	Roof raised	525'
22,300	1906	Bridgeport	Black powder	1760'	Poorhouse	Windows broken, chimney down	880'
22,500	1906	Jellico	Dynamite	1000'	Frame dwelling	Wall collapsed	500'
24,000	1901	Vestal Station	Dynamite	1200'	Farm buildings	Rafters broken	600'
24,300	1906	Yreka	Dynamite	1320'	Dwelling	Chimney broken, windows broken	660'
25,000	1907	Fontanet	Black powder	600'	Light frame construction	Slight damage	300'
25,000	1881	Council Bluffs	Dynamite	1320'	Railroad building	Much structural damage	660'
26,400	1908	Pinole	Dynamite	1150'	Light frame construction	Roof damaged	1150'
26,700	1902	Carabanchel	Mixed expl.	660'	Old masonry building	Badly shaken	660'
27,000	1871	Stowmarket	Guncotton	1500'	Masonry church	Gable ends blown in	750'
27,500	1903	Lowell	Black powder	1640'	Dwelling house	Seriously damaged	825'
30,000	1907	Reddick	Dynamite	1300'	Grain elevator	Roof damaged	650'
32,000	1863	Ft. Lyons	Black powder	1050'	House	Windows and door blown in	1050'
34,000	1904	Coolgardie	Dynamite	600'	Above ground magazine	Unroofed	600'
37,500	1907	Connable	Black powder	600'	Frame office building	Side torn out	600'
41,[illegible]	1895	Keeken	Dynamite	3940'	House	Brick wall cracked	1970'
44,950	1908	McAlester	Black powder	1000'	Dwelling	Chimney down, windows out	500'
45,000	1905	Fairchance	Black powder	3300'	Dwellings	Damaged	1650'
[illegible]	1904	Jackson	Dynamite	[illegible]	Dwelling	[illegible]	[illegible]
[illegible]	[illegible]	Santander	Dynamite	[illegible]	Masonry buildings	Floors, walls and ceiling fell in	1650'
83,500	1864	Erith	Black powder	4660'	Brick railway station	Wall down	2330'
110,700	1890	Johannesburg	Gelatin	3000'	Mud with iron roof	Roofs battered in	1500'
162,000	1886	Chicago	Black powder	3000'	Wood frame dwelling	Broken rafters; windows out	1500'
165,000	1800	Beira	Black powder	660'	Masonry Buildings	Destroyed	660'
175,000	1769	Brescia	Black powder	1970'	Masonry Buildings	Greatly injured	[illegible]
[illegible]	1892	Highland Station	Dynamite	2600'	Light frame construction	Roof crushed	[illegible]
875,000	1907	Fontanet	Black powder	4000'	Frame dwelling	Rafters broken, windows out	2000'

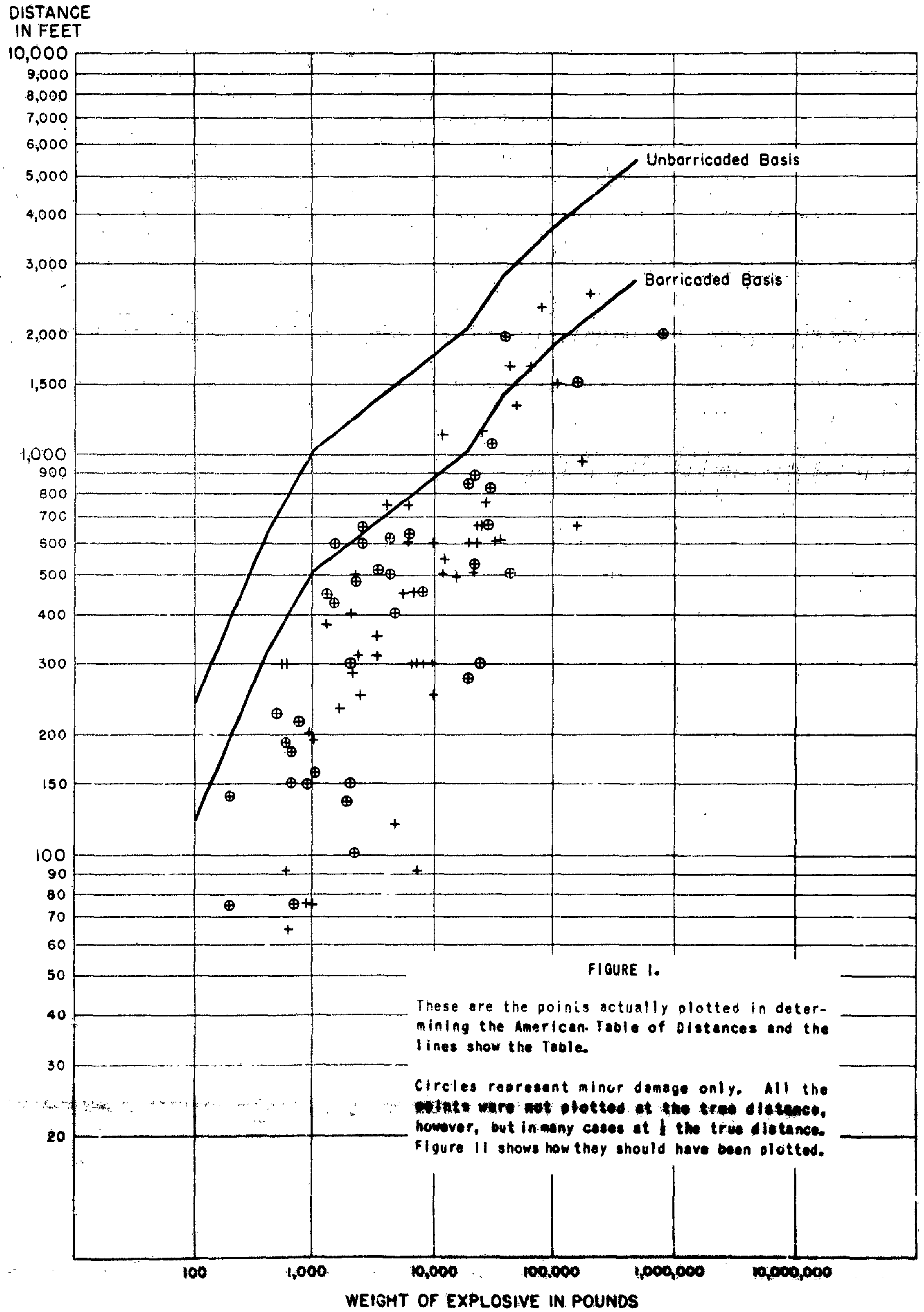

FIGURE I.

These are the points actually plotted in determining the American Table of Distances and the lines show the Table.

Circles represent minor damage only. All the points were not plotted at the true distance, however, but in many cases at ½ the true distance. Figure II shows how they should have been plotted.

rebuilding.* In 58 of the 92 cases, the explosion occurred behind a shield or some sort of natural or artificial barricade, while in 34 of the cases it was not so shielded.

In determining the values for the American Table of Distances, all 92 of these explosions were used, but no attention was given to the 25 involving window breakage only. The method consisted in plotting the maximum reported distance against the weight of explosive involved, and those who prepared the table elected to plot the 58 cases where the explosion was barricaded. In order, however, to include the 34 cases where there was no shielding, for reasons which no doubt appeared sound to them in 1910, but which at the present time seem without any foundation whatever, they divided the actual reported distances by two and so plotted them. This gives the plot shown in Figure I, which, in order to make it readable, has been plotted on a logarithmic scale. The points with circles indicate "minor damage" only, while those without indicate "more serious damage." The lower line shows the values in the American Table of Distances for barricaded explosives, while the upper line is on the unbarricaded basis.

Figure I, while showing the exact procedure used in developing the American Table of Distances, gives a false picture of the facts on account of the method of using half the reported distance, so Figure II was drawn to show what it should look like when the actual reported distances are used in all 92 cases.

Since the American Table of Distances was published in 1910, there have been 66 additional explosions for which reliable data are available. The total amount of explosives involved in these 66 explosions was 28,250,000 pounds. This is in contrast to the 92 explosions plotted before 1910 where the total amount of explosives involved was 2,719,000 pounds. The 66 later explosions, 1910 to 1945, have been collected in Table II. The maximum distance at which damage was reported is listed in this table, and in most cases this damage is greater than that listed for the explosions which were used in determining the American Table of Distances. These maximum distances have been plotted on Figure III, and the two lines showing the American Table of Distances have been added as before for reference purposes.

A comparison of Figures II and III shows that before 1910 there were only 3 explosions which did "more serious damage" at distances beyond those given by the unbarricaded basis line of the American Table of

---

* The following classification of structural damage is used:

Class A - Complete demolition
Class B - Partial demolition but beyond repair
Class C - Unusable but capable of being repaired
Class D - Usable but urgently needing repairs
Class E - Minor damage, usable without repairs
Class F - Broken glass

In this paper, Classes A,B,C, and D are included in "more serious damage."

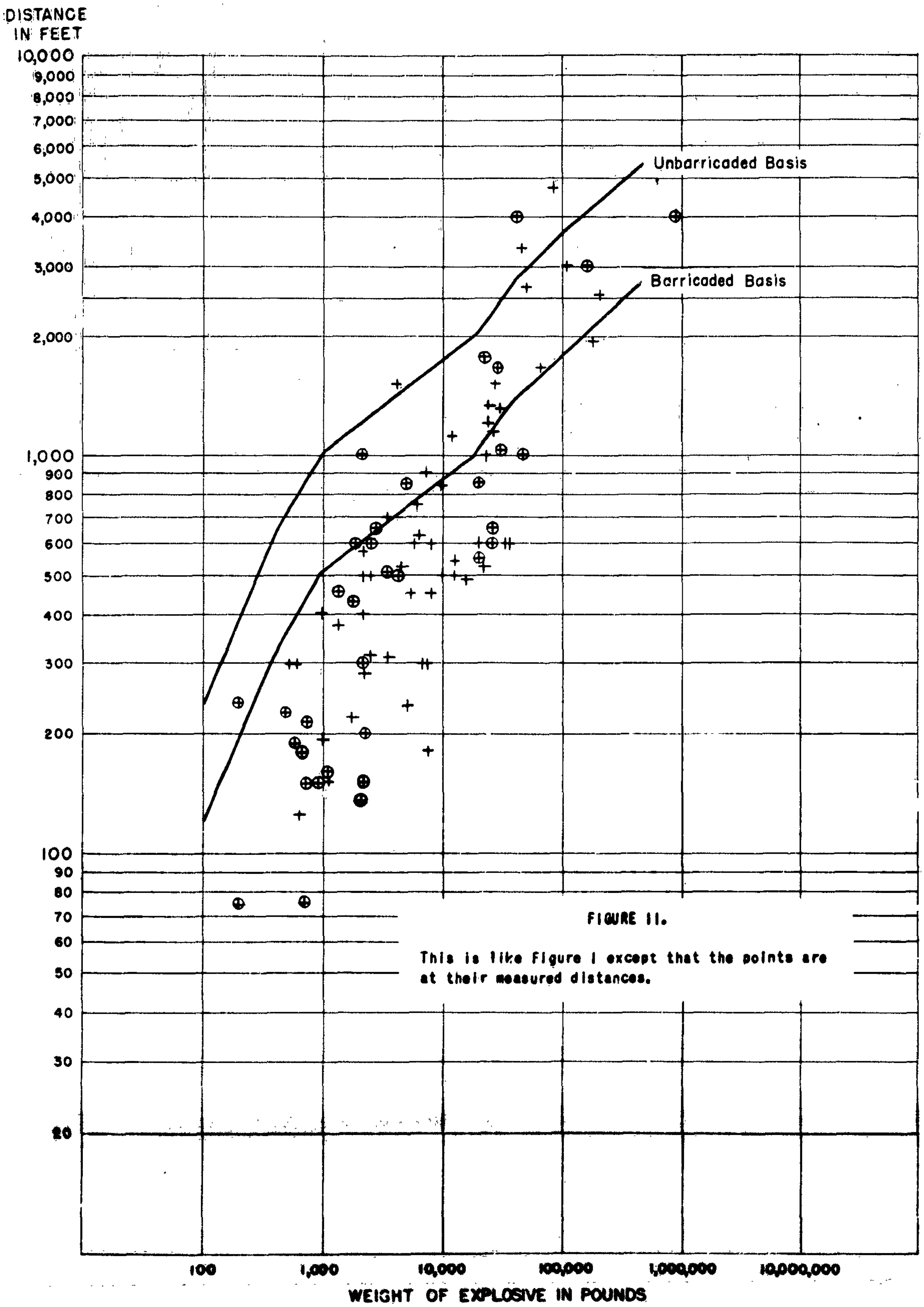

FIGURE 11.

This is like Figure I except that the points are at their measured distances.

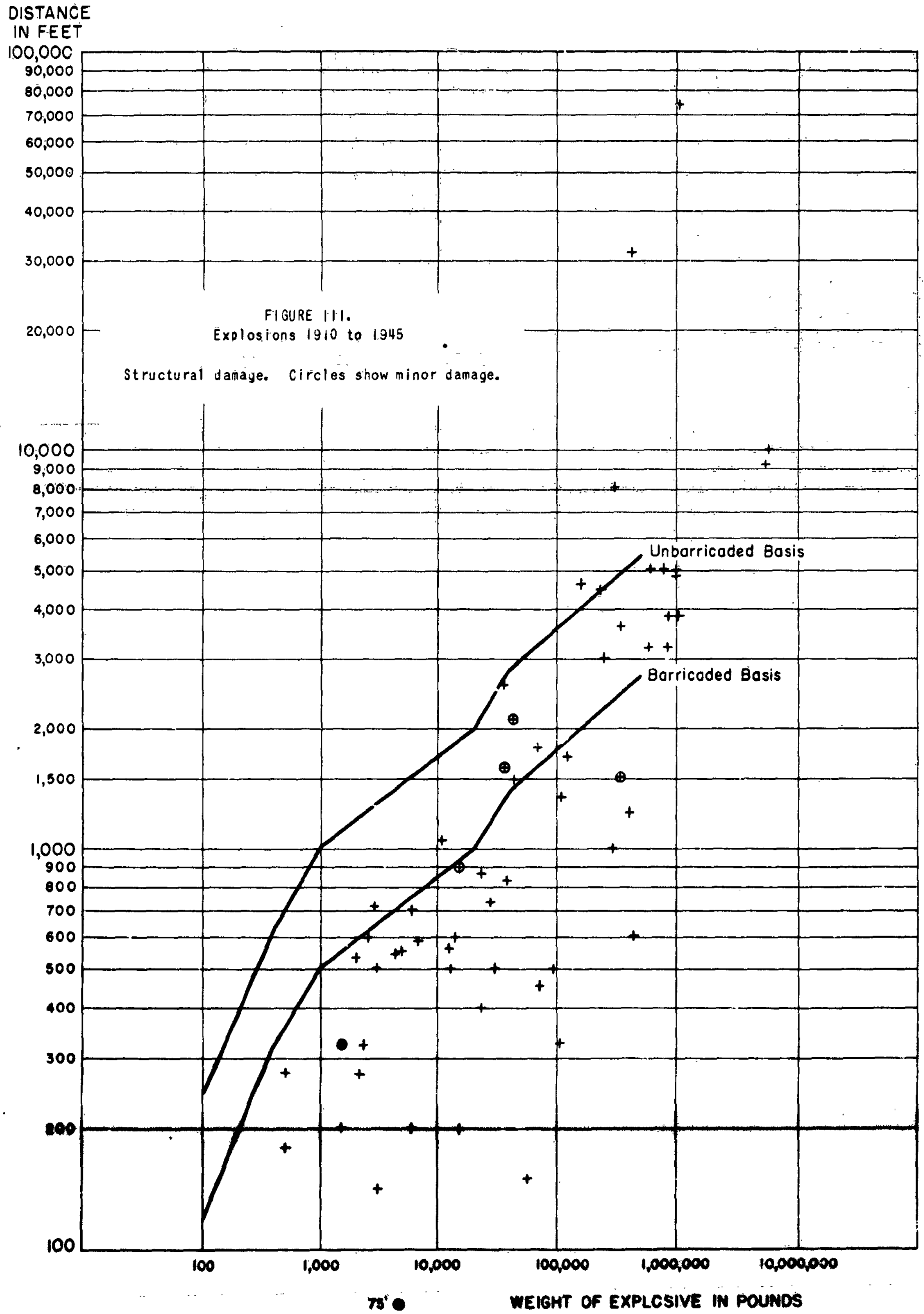

FIGURE III.
Explosions 1910 to 1945

Structural damage. Circles show minor damage.

TABLE II

EXPLOSIONS FROM 1910 TO 1945

Weight of Explosive	Date	Place	Kind of Explosive	Maximum Distance for "More Serious Damage"
500 #	1910	Jeanette	Dynamite	180 feet
500	1944	Topeka	Smokeless powder	275
800	1943	Elkton	Tracer Mixture	100
1,000	1910	Robert's Landing	Nitrostarch	500
1,500	1912	Schaghticoke	Black powder	325 ("minor damage" only)
1,500	1941	Burlington	H.E.	200
2,000	1944	London	V-1 Bomb	540
2,030	1944	ETO	Bombs	270
2,300	1913	Gibbstown	Gelatin	320
2,500	1918	Morgan	Amatol	600
2,793	1911	Nanaimo	Dynamite	720
3,000	1910	Pinar Del Rio	Dynamite	140
3,000	1913	Martin	Dynamite	500
4,180	1914	Ardeer	N.G.	546
4,500	1943	Kankakee	DNT	75 ("minor damage" only)
4,650	1912	Haskell	N.G.	550
6,000	1910	Cabot	Black powder	200
6,000	1943	Norfolk	H.E.	700
6,700	1913	Hazardville	Black powder	590
9,500	1910	Hull	Chlorate explosive	400
10,280	1944	Soham	Bombs	1050
12,000	1910	Beloeil	N.G.	560
12,700	1944	Bedford	Dynamite	500
13,600	1945	MTO	Bombs	600
15,000	1911	Communipaw	Dynamite	200
15,000	1944	ETO	Mixed ammunition	900 ("minor damage" only)
21,000	1912	Wilpen	Black powder	75
22,440	1913	Tacubayo	Black powder	365
23,100	1911	San Jose	Black powder	400
26,750	1912	Newburgh Heights	Dynamite	730
30,000	1944	Hereford	Bombs	500
33,600	1915	Seattle	Gelatin	2560
34,000	1914	Panama City	Black powder	825
35,000	1945	ETO	Mines	1600 ("minor damage" only)
41,000	1943	Portage	Bombs	2100 ("minor damage" only)
45,000	1945	MTO	Bombs	1500
48,000	1945	ETO	Bombs	1500
57,000	1942	Elwood	TNT	150
65,000	1940	Kenvil	Smokeless powder	1800
70,000	1945	ETO	Dynamite	450
96,250	1913	Nanaimo	Dynamite	500
103,400	1913	San Antonio	Dynamite	327
104,000	1943	Yorktown	H.E.	1350
120,000	1944	Hastings	H.E.	1700
150,000	1918	Morgan	TNT	4600
234,000	1917	Haskell	Smokeless powder	4440
248,000	1925	Rio de Janeiro	Dynamite	3000 (missile distance)
300,000	1944	Bombay	H.E.	1000
301,000	1910	Kobe	Dynamite	8000
342,200	1912	Vienna	Smokeless powder	3600
346,000	1924	Manila	Dynamite	1500 ("minor damage" only)
400,000	1916	Black Tom	H.E.	1220
450,000	1914	Mindi	Dynamite	600
591,000	1945	MTO	Bombs	5000
600,000	1913	Baltimore	Dynamite	3200
800,000	1945	ETO	Bombs	5000
825,000	1918	Morgan	Ammonium nitrate	3200
860,000	1918	Morgan	Amatol	3800
1,000,000	1918	Morgan	Ammonium nitrate	3800
1,000,000	1918	Morgan	Ammonium nitrate	4800
1,000,000	1921	Oppau	Ammonium nitrate	5000
1,100,000	1944	Hastings	Bombs and warheads	14 miles (flimsy structure)
[illegible]	1926	Lake Denmark	TNT	5400
[illegible]	1944	Port Chicago	Bombs, etc.	4 miles (flimsy structure)
[illegible]	1917	Halifax	H.E.	[illegible]
5,500,000	1917	Steinfeld	H.E.	10,000

Distances and none of these involved more than 100,000 pounds. Between 1910 and 1945, however, there have been 7 explosions for which the American Table of Distances would not have protected the surroundings against "more serious damage," and each of these was an amount greater than 100,000 pounds.

The explosions listed in Table I and Table II total 158 items and the total weight of explosives involved was 31,000,000 pounds. The total loss of life as reported was 6167. This is the equivalent of 1 person killed by an accidental explosion for every 5000 pounds of explosive involved.

In a study of accidental explosions, particularly the maximum distance at which a certain class of damage is reported, it should be remembered that the reported distance is always less than the possible maximum. For example, suppose there occurs an explosion of such magnitude that it could do structural damage as far away as 1000 yards. But if the most distant structure in the neighborhood was only 100 yards away, the damage would necessarily be reported as 100 yards. For this reason, it must be assumed that damage from a given amount of explosive may occur at greater distances than any thus far reported.

The primary basis for the American Table of Distances was the explosion which takes place behind a shield or barricade. However, it is now generally recognized that, except in very special circumstances, barricades around the explosive are of no effect in reducing the maximum distance at which structural damage occurs. For proof, see Figure 21 in the author's text, "Explosions: Their Anatomy and Destructiveness." It appears, therefore, that in using the American Table of Distances for the protection of the public and of public property, the table for unbarricaded explosives only should be used.

A comparison of Figures II and III shows that for "more serious damage," the American Table of Distances on the unbarricaded basis gives unnecessarily great distances for small amounts of explosives, but for large quantities it is grossly inadequate. This latter is particularly unfortunate at the present time since the unavoidable concentrations of explosives at shipping points and ports of embarkation may necessitate the presence of many millions of pounds of high explosives at a single such location with the corresponding increased hazard to the public and to public property. And since safety distances for the public are at present based almost exclusively on the American Table of Distances, the possibility of a major catastrophe is by no means negligible. The safety distances prescribed by the British War Office recognize this situation and, (where great concentrations are involved) require from 3 to 4 times the distance required in this country.

It will be noted that none of the explosions before 1910 involved modern military explosives, such as TNT, Amatol, Smokeless powder and the like. Since that time there have been 36 cases where quantity-distances involving more serious structural damage were reported for such explosives. These data have been collected in Table III and plotted in Figure IV, which also has the reference lines from the American Table of Distances. The line marked "Actual Boundary - no factor of safety"

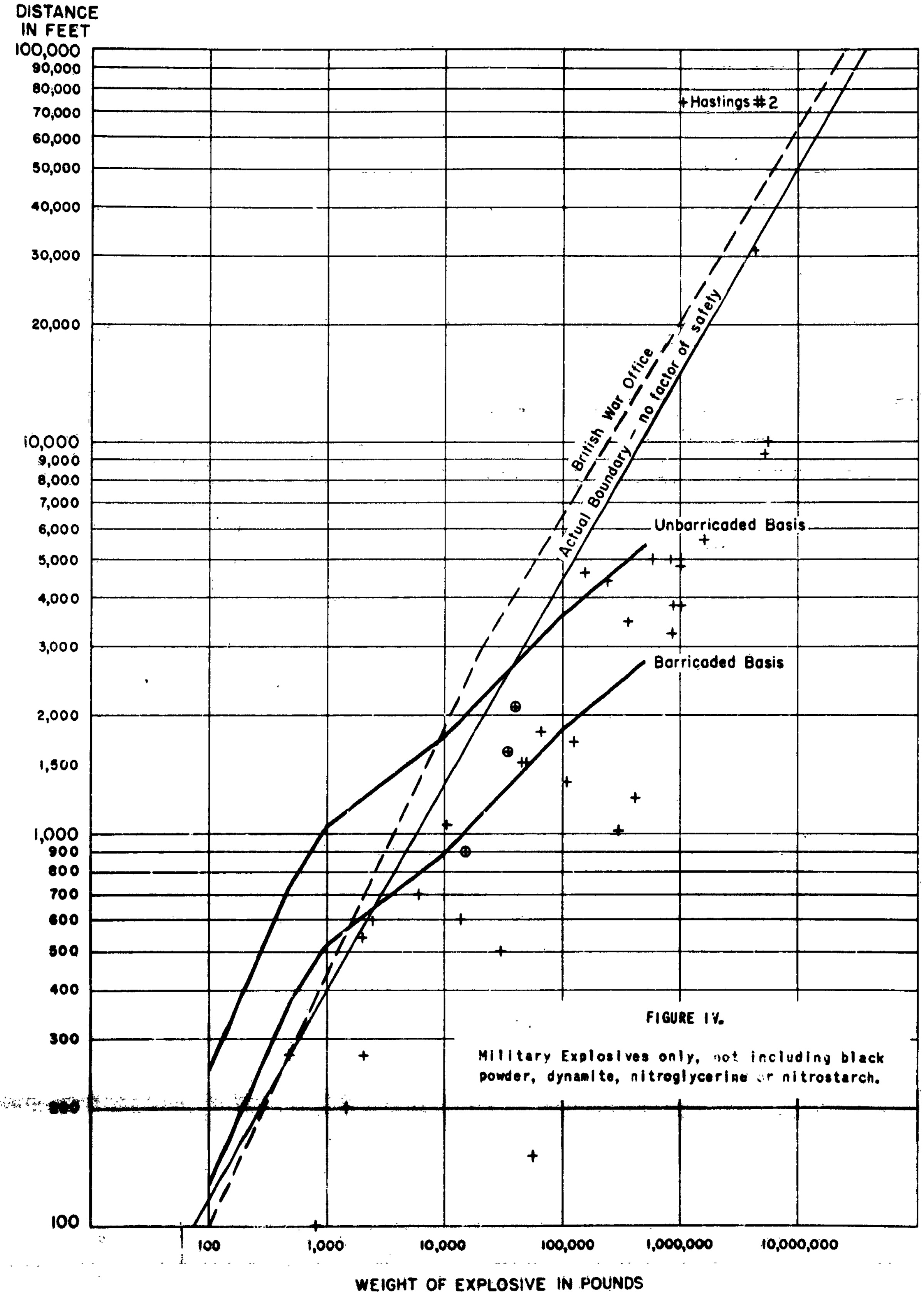

FIGURE IV.

Military Explosives only, not including black powder, dynamite, nitroglycerine or nitrostarch.

TABLE III

Accidental Explosions with Military Explosives*

* not including black powder, dynamite, nitroglycerine, etc.

Weight (#) of Explosives	Date	Place	Kind of Explosive	Maximum Distance for "More Serious Damage"
500	1944	Topeka	Smokeless Powder	275'
800	1943	Elkton	Tracer mixture	100
1,500	1941	Burlington	TNT	200
2,000	1944	London	V-1 Bombs	540 (avera. max. of 2300 bombs)
2,080	1944	ETO	Bombs	270
2,500	1918	Morgan	Amatol	600
6,000	1943	Norfolk	Torpex	700
10,280	1944	Soham	Bombs	1050
13,600	1945	MTO	Bombs	600
15,000	1944	ETO	Ammunition	900 ("minor damage" only)
30,000	1944	Hereford	Bombs	500
35,000	1945	ETO	Mines	1600 ("minor damage" only)
41,000	1943	Portage	Bombs	2100 ("minor damage" only)
45,000	1945	MTO	Bombs	1500
48,000	1945	ETO	Bombs	1500
57,000	1942	Elwood	TNT	150
65,000	1940	Kenvil	Smokeless powder	1200
104,000	1943	Yorktown	Torpex	1850
120,000	1944	Hastings	Torpex	1700
150,000	1918	Morgan	TNT	4600
234,000	1917	Haskell	Smokeless powder	4440
300,000	1944	Bombay	High Explosives	1000
342,000	1912	Vienna	Smokeless powder	3600
400,000	1916	Black Tom	High Explosives	1220
591,000	1945	MTO	Bombs	5000
800,000	1945	ETO	Bombs	5000
825,000	1918	Morgan	NH_4NO_3	3200
860,000	1918	Morgan	Amatol	3800
1,000,000	1918	Morgan	NH_4NO_3	3800
1,000,000	1918	Morgan	NH_4NO_3	4800
1,000,000	1921	Oppau	NH_4NO_3	5000
1,100,000	1944	Hastings	Torpex bombs, etc.	14 miles
1,600,000	1926	Lake Denmark	TNT	5600
4,272,000	1944	Port Chicago	Torpex bombs, etc.	6 miles
5,200,000	1917	Halifax	High explosives	9240
5,500,000	1917	Steinfeld	High explosives	10000

TABLE IV

Weight of Explosive	American Table of Distances	Actual Boundary (feet)	Weight of Explosive	American Table of Distances	Actual Boundary (feet)
50	145	90			
100	240	120	70,000	3,220	3,720
200	360	180	80,000	3,390	3,990
300	520	220	90,000	3,520	4,200
400	640	250	100,000	3,630	4,490
500	720	280	125,000	3,670	5,050
600	800	310	150,000	3,800	5,550
700	860	340	175,000	3,930	6,030
800	920	360	200,000	4,060	6,460
900	980	380	250,000	4,310	7,260
1,000	1,020	400	300,000	4,550	7,930
1,500	1,060	500	350,000	4,780	8,670
2,000	1,200	580	400,000	5,000	9,290
3,000	1,300	710	450,000	5,210	9,660
4,000	1,420	830	500,000	5,410	10,400
5,000	1,500	940	600,000		11,500
6,000	1,560	1,040	700,000		12,500
7,000	1,610	1,130	800,000		13,400
8,000	1,660	1,210	900,000		14,200
9,000	1,700	1,280	1,000,000		15,000
10,000	1,740	1,340	2,000,000		21,600
15,000	1,780	1,660	3,000,000	End of American Table of Distances	26,700
20,000	1,950	1,930	4,000,000		31,100
25,000	2,110	2,170	5,000,000		35,000
30,000	2,260	2,330	6,000,000		38,500
35,000	2,410	2,590	7,000,000		41,800
40,000	2,550	2,770	8,000,000		44,800
45,000	2,680	2,930	9,000,000		47,700
50,000	2,800	3,120	10,000,000		50,400
60,000	3,030	3,430	15,000,000		62,200

represents the limiting distance for more serious damage to structures with the exception of one point for which there is no good explanation at present but for which there is no doubt as to the data. The line marked "British War Office" is the safety distance required by that Office for high explosives. In order to compare the "Actual Boundary" line with that from the American Table of Distances, Table IV has been compiled using the customary weight intervals.

In order to put the quantity-distance relationship for damage to structures from explosions on a technically quantitative basis, the maximum distance at which more serious damage was reported for all 158 accidental explosions studied was averaged and the results are given in Table V. In this table are also the corresponding peak or maximum pressures, the positive impulse and the duration for the positive pressure. These values were computed from information in the possession of the Board and which is believed accurate to 25%.* The impulse is the pressure times its duration and represents the push of the blast wave.

TABLE V

Averaged Maximum Distances for "More Serious Damage"

Weight of Explosive in Pounds	Distance from the Explosion in Feet	Peak Pressure in Pounds per Square In.	Impulse Pounds-Seconds per Square In.	Pressure Duration in Seconds
100	72	3.2	.016	.010
1,000	200	2.3	.027	.024
2,000	270	2.1	.033	.031
10,000	550	1.6	.044	.055
100,000	1,530	1.4	.076	.11
1,000,000	4,150	.95	.13	.27
10,000,000	11,300	.75	.23	.61

The difference between Table V and Table IV lies in the distinction between "Average Maximum Distance" and "Actual Boundary of Damage." Table IV shows the greatest distances at which more serious damage has actually been reported, while Table V shows the distances up to which it may be expected. Table V gives *probable* distance while Table IV gives *possible* distance.

From a technical standpoint the peak pressure as shown in Table V is seen to have but a 4-fold range while the corresponding weight of

* The relations between the Peak Pressure Distance in feet (r), the Weight of explosive in pounds (w), and the Peak Pressure in pounds per square inch (p) is given by the formula.

$$r = 0.76\left[\log^{1}\left(\frac{5000}{p}\right)^{0.115}\right]\left(\frac{w}{1000}\right)^{1/3}$$

The pressure is the side-on, not impact, pressure.

explosive varies over a 100,000-fold range. This indicates that within the limits of precision of the data, selecting an average peak pressure of 2 pounds per square inch will permit an estimate of the maximum distance at which "more serious damage" is probable, as based on pressure effects alone. The advantage of this is that it makes it possible, using recognized relationships, to estimate the advantage of any device that acts so as to reduce the peak pressure from a given explosion at a given distance.

The "Intraline Distance" as given in the Ordnance Safety Manual (1945 Edition), this distance being the minimum between buildings handling explosives in a single operating or manufacturing line, is an excellent example of the use of a fixed average peak pressure for determining limiting distances for structural damage. This is shown in Table VI.

TABLE VI

Intraline Distances (from Ordnance Safety Manual)

Weight of Explosives in Pounds	Intraline Distance in Feet	Peak Pressure in Pounds per Square In.
100	80	2.8
1,000	190	2.5
10,000	400	2.5
100,000	850	2.7
250,000	1,150	2.7

Average Peak Pressure = 2.6

On this basis of this constant peak pressure, the "Intraline Distance" could be extrapolated to larger quantities of explosive, as follows:

Weight of Explosives in Pounds	Intraline Distance in Feet	Peak Pressure in Pounds per Square In.
1,000,000	1800	2.6
10,000,000	3850	2.6

The use of the "Intraline Distance" therefore, gives a plant more than an even chance of more serious structural damage.

25-68153-1003